Digital Switching Wireless Receiver Diversity and Buffer Diversity for Enhanced Reception in a Wireless Digital Audio Communication System

Background of the Invention

Field of the Invention

[0001] This invention relates to methods and apparatus for the transmission and reception of the broadcast signals modulated with encoded data. More particularly this invention relates to methods and apparatus for reception of broadcast signals modulated with encoded data employing receiver diversity and time diversity techniques.

Description of Related Art

[0002] Diversity techniques are well known in the art to insure the quality of reception in an environment where the broadcast signals are fading. Transmitter diversity employs multiple antennas or multiple transmitters coupled to multiple antennas to broadcast signals such that a receiver is more likely to receive one of the signals.

[0003] In receiver diversity, multiple antennas or multiple antennas coupled to multiple receivers are employed to receive the broadcast signal. In the fading channel, the likelihood that one of the receivers will capture the broadcast signal justifies the expense of additional antennas and receivers.

[0004] Refer now to Figs. 1a and 1b for a review of receiver diversity of the prior art. In Fig. 1a, the transmitter **5** modulates a transmit signal such as an RF frequency with a data signal and transfers the modulated transmit signal to a transducer such as the antenna **10**. The antenna **10** radiates a broadcast signal that results from the modulated transmit signal. The broadcast signal as is known is a wave front of electromagnetic energy shown here as separate broadcast signals **12**, **13**, and **14**. Geographic obstacles such as mountains and hills **15** and buildings **20** may block or reflect the broadcast signals **12**, **13**, and **14** such that the amount of energy arriving at any of the antennas **25a**, **25b**, **25c** is not sufficient to be detected by the receiver **35**. If there were just one antenna, then any of the broadcast signals **12**, **13**, and **14** cannot be distinguished by the receiver. However, the multiple antennas **25a**, **25b**, **25c** allow the antenna switch **30** to monitor the strength of the received broadcast signals **12**, **13**, and **14** and to select one of the antennas **25a**, **25b**, **25c** having the strongest signal for transfer to the receiver **35**. This allows the receiver **35** to have the highest quality signal to process to extract the received information.

[0005] In Fig. 1b, the transmitter **5** similarly modulates a transmit signal such as an RF frequency with a data signal and transfers the modulated transmit signal to a transducer such as the antenna **10**. The antenna **10** radiates a broadcast signal that results from the modulated transmit signal. The broadcast signal, as is known, is a wave front of

electromagnetic energy shown here as separate broadcast signals **12**, **13**, and **14**. The geographic obstacles such as the mountains and hills **15** and the buildings **20** similarly may block or reflect the broadcast signals **12**, **13**, and **14**. In this example, the antennas **25a**, **25b**, **25c** are coupled respectively to the receivers **35a**, **35b**, **35c**. Dependent upon the strength of the broadcast signals **12**, **13**, and **14** any of the antennas **25a**, **25b**, **25c** may not have sufficient for detection by its respective receiver **35a**, **35b**, **35c**. As in the previous example, if only one antenna and receiver existed and it was blocked from receiving the broadcast signals **12**, **13**, and **14**, the receiver would not be able to recover the data signal. All the receivers **35a**, **35b**, or **35c** are connected to the receiver switch **40**, which dependent upon the quality of the received and recovered signal switches selects the receiver **35a**, **35b**, **35c** having the best recovered data signal.

[0006] The examples of Figs. 1a and 1b illustrate a wireless radio frequency (RF) application for diversity. Refer now to Fig. 2 for an example of receiver diversity as applied to a wireless infrared application for digital audio headphones. The transmitter **50** is provided digitally encoded audio signals. The transmitter **50** formats the digitally encoded audio signals with synchronization, control, and error signals. The formatted encoded data modulates a transmit signal similar to the RF wireless, except in this case the signal may be pulse positioned modulated rather than frequency shift keyed as in RF wireless. The modulated signal is used to control the radiation of a light signal from the light emitting diode

(LED) **55**. The light signal **85** is broadcast to the headphones **60**. The headphones **60** have at least two photodetectors **70a** and **70b**. The photodetectors **70a** and **70b** are generally placed on the outer sides of the headphones **60** to receive the light signal **85**. The detected electrical signals of the photodetectors **70a** and **70b** are transferred to the receiver **75**, which demodulates and reformats the encoded audio signals for transfer to the speakers **80a** and **80b**. The speakers **80a** and **80b** are placed in close proximity to the ears of the person **65** wearing the headphones **60**. If the system had only one photodetector **70a** or **70b**, the light signal **85** would be not be detectable if the photodetector **70a** or **70b** was not pointed essentially directly at the LED transmitter **55**. Having two photodetectors **70a** and **70b** allows the receiver to always have detected electrical signals. The photodetectors **70a** and **70b** maybe selected by a switch that which of the photodetectors **70a** or **70b** has sufficient signal for detection. Alternately, there, in fact, may be two receivers with a selection circuit determining which receiver transfers the received audio to the speakers **80a** and **80b**.

[0007] A technique commonly referred to as time diversity employs interleaving of the encoded data and error correction coding to insure that the received digital audio signals are recovered. The interleaving separates contiguous data packets of the digital audio and transfers them at non-contiguous times. This allows for errors to occur within the encoded data and to the encoded data to be recovered when the received

digital audio data is rearranged to de-interleave the data packets and then have error detection and correction performed on the received data. Thus even marginally received broadcast signals can be successfully received and the data recovered.

[0008] U.S. Patent 6,351,630 (Wood, Jr.) describes a wireless communications system having transponder coupled to one of multiple selectable antennas. A look-up table holds data representing antennas, and having pointers to define an order in which antennas will be used to attempt communication with second transponder

[0009] U.S. Patent 6,272,190 (Campana, Jr.) provides a system and method for wireless transmission and receiving of information. The method includes transmitting data and then after a time delay retransmitting the data. The data for each transmission contains an error correction code. Upon receiving the first and second data transmissions, the data is processed to identify, by use of the error correction code, erroneous data within at least one of the data transmissions. The identified erroneous data is replaced with non-erroneous data from the other data transmission.

[0010] U.S. Patent 6,185,258 (Alamouti, et al.) teaches a transmitter diversity technique for wireless communications. A simple block coding arrangement is created with symbols transmitted over a plurality of

transmit channels. The diversity created by the transmitter utilizes space diversity and either time or frequency diversity.

[0011] U.S. Patent 6,181,749 (Urabe, et al.) details a diversity receiver. A demodulator obtains modulated data to a number of channels. The channels have subband filters and differential detectors for demodulating the data. Error estimating circuits estimate and output the numbers of erroneous symbols and error locations for each channel. A data comparator compares the demodulated data corresponding to the error locations with the demodulated data in the corresponding locations in other channels to determine whether the error location is correct. The data comparator provides a decision signal in response to the determination. A data selector selects one of the demodulated data from the channels on the basis of the numbers of erroneous symbols and the decision signals and outputs the data as selected data.

[0012] U.S. Patent 6,088,407 (Buternowsky, et al.) describes a digital diversity receiver system employing one or more transmitters, a plurality of receivers, and at least one two-way personal paging unit or pager. The two-way pager receives pages from the transmitter, and sends response signals, which are detected by the receivers. A microdiversity receiver is described as two receiver components provided at a single receiver site, with a separate antenna for each receiver component. Signals as received at the different receivers can be compared and have the

accuracy indication information combined to increase the reliability of the system in detecting and decoding the pager response symbols.

[0013] U.S. Patent 5,799,042 (Xiao) describes a wireless digital communication systems that apply an antenna diversity scheme to combat fading in a received radio system having a single receiver front-end comprises a simple and robust antenna diversity scheme. Radio signals transmitted to the receiving antennas has redundant information for allowing error correction at reception side.

[0014] U.S. Patent 5,073,900 (Mallinckrodt) provides a cellular communications system is provided using spread spectrum system with code division multiple access (CDMA), and employing forward error correction coding (FECC) to enhance the effective gain and selectivity of the system. A digital data interleaving feature reduces fading.

[0015] U.S. Patent 4,517,669 (Freeburg, et al.) describes a method and apparatus for coding messages communicated between a primary station and remote stations of a data communications system. The apparatus employs an antenna diversity scheme for a communications controller at the primary station. Variable length messages are communicated between a general communications controller (GCC) and a plurality of portable and mobile radios. The variable length messages include a bit synchronization field, a message synchronization field and a plurality of channel data blocks for efficiently and reliably handling long strings of data

or text. Each channel data block includes an information field, a parity field for error-correcting the information field and a channel state field indicating whether or not the radio channel is busy or free.

[0016] Japanese Patent Laid-Open No. 4-8031 JP4008031 (Hiroyuki) describes a reception diversity system, which generates an error correcting signal indicating the correction every time received data is corrected. The error correcting signal is sent to an error correcting signal comparator, which counts the error correcting signal compares the signals from multiple receivers to decide which receiver is providing the best quality reception.

[0017] Japanese Patent Laid-Open No. 1-265739 (Kiyoyuki, et al.) provides a system for minimizing the effect of reception level fluctuation and phase fluctuation due to fading. The transmitter sends transmission information converted encoded with error detection and correction codes. The receiver decodes the received information by plural antennas. The system performs an error detection and correction on the received information and based on the amount of errors present in the received information selects the received information from the antenna with least error among the received information sets from each of the antennas.

[0018] "Cochannel Interference Suppression Through Time/Space Diversity," Calderbank, et al., IEEE Transactions on Information Theory, May 2000, Volume: 46, Issue: 3, pp. 922 – 932 discusses wireless

systems that are subject to a time-varying and unknown a priori combination of cochannel interference, fading, and Gaussian noise. The wireless systems discussed provide diversity in time by channel coding.

[0019] "Interference Cancellation Using Antenna Diversity for EDGE-Enhanced Data Rates in GSM and TDMA/136," Bladsjo et al., Proceeding Vehicular Technology Conference, 1999, pp. 1956 – 1960, vol.4, discusses the evaluation of EDGE (enhanced data rates for global evolution). The paper further discusses antenna diversity, which enables interference-cancellation methods.

Summary of the Invention

[0020] An object of this invention is to provide a communication system for transmitting and receiving a broadcast signal modulated with coded data.

[0021] Another object of this invention is to provide a communication system applying diversity to improve reception of coded data in presence of fading of the broadcast signal.

[0022] To accomplish at least one of these and other objects, a communication system includes a transmitter and diversity receiver. The transmitter acquires input data, appends an error coding and a locking signal to the input data to form the coded data. The transmitter then modulates the broadcast signal with the coded data, and propagates the

broadcast signal through a transmitting transducer. The transmitting transducer maybe an antenna or a light emitting diode.

[0023] The diversity receiver system receives the coded data modulated broad cast signal from a transmission channel. The transmission channel is characterized by multiple transmission paths having variable transmission time and variable attenuation characteristics causing multiple copies of the coded data modulated broadcast signal. The diversity receiver system has a signal acquisition device in communication with the transmission channel for reception of the multiple copies of the coded data modulated broadcast signal. The signal acquisition device evaluates signal characteristics of one or more copies of the multiple copies of the coded data modulated broadcast signal, extracts the coded data, control signals, and locking signals from the one or more copies of the multiple copies of the coded data. A diversity circuit is in communication with the signal acquisition device to receive the signal characteristics and the coded data, the control signals, and locking signals, the diversity circuit selecting from the signal characteristics, the control signals, and the locking signals, one of the copies of the coded data modulated broadcast signals. The diversity receiver has an error evaluation circuit in communication with the diversity circuit to receive the coded data from the selected copy of the coded data modulated broadcast signal. The error evaluation circuit evaluates the coded data signal for errors and providing an error signal to the diversity circuit indicating an error state of the

selected data, wherein the diversity circuit selects a second copy of the coded data modulated broadcast signal.

[0024] The signal acquisition device includes a plurality of receiving transducers, such as antennas or photodiodes, such as antennas or photodiodes, in communication with the transmission channel. Each transducer acquires one of the copies of the coded data modulated broadcast signal from the transmission channel and converting the copy of the coded data modulated broadcast signal to a received electrical signal. The received electrical signal varies in magnitude dependant upon the transmission time and variable attenuation characteristics of the transmission channel. In a first embodiment, the signal acquisition device has a plurality of receivers. Each receiver is in communication with one of the receiving transducers to amplify and condition the electrical signal and to extract the coded data, control signals, and locking signals from the received electrical signal.

[0025] Each of the plurality of the receiving transducers is assigned a selection priority such that the receiver in communication with a receiving transducer of a highest priority is selected by the diversity circuit. If the error signal indicates the selected data is in error, the diversity circuit determines another receiver having a valid locking signal and transfers the data of the receiver to the error evaluation circuit. Alternately, if the error

evaluation circuit indicates the selected data is in error but is correctable, the error evaluation circuit corrects the selected data.

[0026] A second embodiment of the signal acquisition device has a plurality of receiving transducers, such as antennas or photodiodes, in communication with the transmission channel. Each transducer acquires one of the copies of the coded data modulated broadcast signal from the transmission channel and converting the copy of the coded data modulated broadcast signal to a received electrical signal. The plurality of receiving transducers is in communication with a transducer switch, which, in turn is in communication with the diversity circuit. Upon reception of a transducer selection signal from the diversity circuit the transducer switch selects one of the electrical signals of a selected receiving transducer. A receiver is in communication with the transducer switch to amplify and condition the electrical signal from selected receiving transducer and to extract the coded data, control signals, and locking signals from the received electrical signal. The error evaluation circuit transfers the coded data to the error evaluation circuit. Each of the plurality of the receiving transducers is assigned a selection priority such that the receiving transducer of a highest priority is selected by the diversity circuit. If the error signal indicates the coded data received and extracted from the electrical signal of the selected receiving transducer is in error, the diversity circuit generates the transducer selection signal to select a second electrical signal from a second receiving transducer to be

transferred to the receiver, the second electrical signal then having a valid locking signal and transfers the data of the receiver to the error evaluation circuit. Alternately, if the error evaluation circuit indicates the coded data received and extracted from the electrical signal of the selected receiving transducer is in error but is correctable, the error evaluation circuit corrects the coded data received and extracted from the electrical signal of the selected receiving transducer.

[0027] The diversity receiver includes a data register in communication with the diversity circuit to retain the coded data received and extracted from the electrical signal of the selected receiving transducer and in communication with the error evaluation circuit so that the error evaluation circuit can retrieve the coded data. A de-interleaving circuit in communication with the diversity circuit to organize the selected data such that the coded data received and extracted from the electrical signal of the selected receiving transducer is in a contiguous order prior to transfer to the error evaluation circuit.

Brief Description of the Drawings

[0028] Figs. 1a and 1b are diagrams illustrating the concept of receiver diversity for a wireless RF communication system of the prior art.

[0029] Fig. 2 is a diagram illustrating the concept of receiver diversity for a wireless infrared communication system of the prior art.

[0030] Fig. 3 is block diagram of a communication system employing diversity reception of this invention.

[0031] Fig. 4 is block diagram of a transmitter of the communication system of this invention.

[0032] Fig. 5 is a flow chart of the method for formatting and transmitting encoded data of this invention.

[0033] Fig. 6 is a diagram illustrating the format of the encoded data of this invention.

[0034] Fig. 7 is block diagram of a first embodiment of the diversity receiver of the communication system of this invention.

[0035] Fig. 8 is a timing diagram illustrating the lock detection of the receiver circuits of the diversity receiver of this invention.

[0036] Fig. 9 is a flow chart of of a first embodiment the method for receiving and recovering the encoded data of this invention.

[0037] Fig. 10 is a timing diagram illustrating the transfer of the data from the transmitter to the receiver and employing receiver and buffer diversity to improve the quality of reception of the encoded data of this invention.

[0038] Fig. 11 is block diagram of a second embodiment of the diversity receiver of the communication system of this invention.

[0039] Fig. 12 is a flow chart of of a second embodiment the method for receiving and recovering the encoded data of this invention.

[0040] Fig. 13 is a timing diagram illustrating the evaluation of the signal characteristics to determine if a received electrical signal from a transducer of the second embodiment of the diversity receiver of this invention.

Detailed Description of the Invention

[0041] The communication system of this invention, as shown in Fig. 3, has a transmitter **100** and a diversity receiver **200**. The transmitter **100** acquires input data and appends an error coding and a locking signal to the input data to form encoded data frame. The transmitter **100** then modulates the broadcast signal with the coded data frame, and propagates the broadcast signal **150** through a transmitting transducer, such as an antenna or light emitting diode.

[0042] The diversity receiver **200** acquires the modulated broadcast signal **150** through multiple receiving transducers. The receiving transducers **200** may include antenna for receiving RF broadcast signals or photodiodes for receiving light broadcast signals. The diversity receiver then extracts the encoded data frame, acquires the locking signal to extract the digital data.

[0043] In a first embodiment, the diversity receiver has multiple receiver circuits each coupled to the receiving transducers. The extracted digital data is de-interleaved. An error detection and correction is performed the de-interleaved digital data and the receiving circuit providing correct digital data is selected for reception of the digital data. The diversity circuit monitors reception of each encoded data frame for control signals and locking signal and the ability to detect and correct errors and transfers the reception to the receiver circuit capturing the locking signal and either capturing the correct digital data or correcting the captured digital data.

[0044] In a second embodiment, the diversity receiver has a transducer switch coupled to each of the multiple transducers. The transducer switch is coupled to one receiver circuit. A select signal determines which of the multiple transducers is to be connected through the transducer switch to the receiver circuit. As in the first embodiment, the diversity circuit monitors reception of each encoded data frame for control signals and locking signal and the ability to detect and correct errors. In the second embodiment the diversity generates the control signal for the transducer switch and transfers the transducer providing the modulated broadcast signal that allows for capturing the control signals, the locking signal and either capturing the correct digital data or correcting the captured digital data.

[0045] The transducers may be provided a selection priority that ensures that a certain transducer is selected initially. The selection priority is modified by the diversity circuit to ensure that the selection a transducer or receiver that ensures capturing the correct digital data or at least capturing correctable digital data.

[0046] Refer now to Fig. 4 for a discussion of the operation of the transmitter **100**. The transmitter **100** acquires the digital data **105** to be transmitted. The digital data **105** may, for example, be the digitally encoded audio signals such as provided by compact disk read only memory. The digital data **105** is received and retained by the data input register **110**. A data clock signal **112** from the synchronization clock circuit **130 110**. An error correction code generator **115** extracts the digital data from the data input register **110** and creates an error correction code that is to be appended to the digital data. The digital data with the appended error correction code is transferred to the interleave circuit **120**. The interleave circuit **120** rearranges the order of the data segments (bytes or words) to separate contiguous data segments. This insures that these data segments will be transmitted in non-sequential order to be separated in time such that the likelihood of errors destroying the digital data is minimized.

[0047] The interleaved digital data is then transferred to the frame format circuit **125**. The frame format circuit **125** will serialize the data and

concatenate a locking signal to the serialized data to form an encoded data frame to be transmitted. The locking signal has a synchronization signal, which is used by the receiver to synchronize its oscillator to the synchronization clock **130** of the transmitter **100**. Additionally, the locking signal has a start signal that indicates the beginning of the serialized digital data. The locking signal may optionally have a stop signal indicating the ending of the serialized digital data.

[0048] The format of the encoded digital data frame is shown in Fig. 6. A digital data frame **190** consists of the locking signal **191**. The locking signal **191** includes the synchronization signal **192** and the start signal **194**. The optional stop signal (not shown) would for the ending message of the encoded data frame. The data interleaves **195a**, **195b**, and **195c** are then serially concatenated after the locking signal **191**. The encoded digital data frames are then serially joined to form the transmission.

[0049] The serialized encoded data is then conveyed to the transmit signal modulator **135**. The transmit signal modulator **135** combines the encoded data with a fundamental no signal to form a modulated transmit signal. The transmit signal modulator **135** would use frequency shift keying for an RF signal and pulse position modulation for a light signal.

[0050] The modulated transmit signal is the input to the transmit driver **140**. The modulated transmit signal provides the stimulus to the

transmitting transducer to cause the modulated broadcast signal **150** to radiate into the environment.

[0051] As is known in the art, the transmitter **100** may include a digital signal processor. The digital signal processor, being a computing system, executes functions and processes being programs stored on data storage medium for execution by the method shown in Fig. 5. The digital frame data is acquired (Box **155**) and retained. The process continues by generating an error correction code (Box **160**) that is to be included with the digital frame data. The digital frame data with the included error correction code is the then rearranged to interleave (Box **165**) the digital frame data to separate contiguous data. As described above, this allows correction of errors that may occur to contiguous transmitted data. The digital data frames are then serialized (Box **170**) and formed (Box **175**) into frames by the concatenation of the locking signal to the digital frame data with the included error correction codes. The locking signal as described above includes the synchronization signal, the start signal, and the optional stop signal. The serialized data frames then modulate (Box **180**) a transmit signal. The modulated transmit signal is then sent (Box **185**) to a transmitting transducer for broadcast to the environment.

[0052] Referring to Fig. 7, the modulated broadcast signal **150**, of the first embodiment, is acquired by a number of transducers **205a**, **205b**, **.., 205n**. The transducers **205a**, **205b**, **... 205n** are placed such that as the

modulated broadcast signal **150** may be fading causing an electrical signal developed by the transducers **205a**, **205b**, ... **205n** to vary with the intensity of the modulated broadcast signal **150**. As described in Figs. 1b and 2, the modulated broadcast signal **150** may be blocked by geographic obstacles such as mountains, hills or buildings. These blockages cause the strength or intensity of the modulated broadcast signal **150** to vary as it arrives at each of the multiple transducers **205a**, **205b**, ... **205n**.

[0053] The electrical signals induced to the transducers **205a**, **205b**, ... **205n** are transferred to the amplification and conditioning circuit **215** within each receiver **210a**, **210b**, ... **210n**. The amplification and conditioning circuit **215** amplifies the electrical signal and removes the fundamental transmit signal from the electrical signal to extract the serialized encoded data. The serialized encoded data is transferred to the clock synchronization circuit **225**, where the synchronization signal is detected and the receiver is synchronized to the frame clock **127** of Fig. 4. When the synchronization signal is detected a synchronization locking signal **227a**, **227b**, ... **227n** for each receiver **210a**, **210b**, ... **210n**.

[0054] The serialized encoded data is also transferred to the start/stop circuit **220**. The start/stop circuit **220** examines the serialized encoded data to detect the start signal within each frame of the encoded data. When the start signal is detected, the start/stop circuit **220** of each receiver **210a**, **210b**, ... **210n** provides a start signal **222a**, **222b**, ... **222n**

indicating the beginning of the interleaved digital data with the included error correction code. The combination of the synchronization locking signal **227a**, **227b**, **... 227n** and the start signal **222a**, **222b**, **... 222n** are combined to form the lock signal as described above.

[0055] The data stream of the serialized encoded data **217a**, **217b**, **... 217n** and the lock signal (synchronization locking signal **227a**, **227b**, **... 227n** and start signal **222a**, **222b**, **... 222n**) for each receiver **210a**, **210b**, **... 210n** are the input signals for the diversity circuit **230**. The diversity receiver searches each lock signal from each receiver **210a**, **210b**, **... 210n** to determine that the receiver is synchronized to the transmitted synchronization locking signal and has detected the start signal. If all receivers **210a**, **210b**, **... 210n** have a lock signal, the diversity circuit **230** chooses one of the receivers **210a**, **210b**, **... 210n** having a highest priority value to provide the data stream of the serialized encoded data **217a**, **217b**, **... 217n**. If the receiver **210a**, **210b**, **... 210n** having the highest priority value chosen does not have a lock signal, the priority value for the receiver is lowered and a next receiver **210a**, **210b**, **... 210n** with the highest priority value is chosen until a lock signal is present.

[0056] Refer to Fig. 8 for a review of the function of the lock signal. The lock signals **255** is shown as a combination of the synchronization locking signal **227a**, and the start signal **222a** from receiver 1 **210a** and the lock signal **260** is shown as a combination of the synchronization locking signal

227b, and the start signal **222b** from receiver 2 **210b**. The received serialized encoded data **190a**, **190b**, **... 190c** consists of the locking signal **191**, which includes the synchronization signal **192** and the start signal **194**, and the encoded data symbols **195**. If the receiver 1 **210a** is not able to acquire either the synchronization signal or the start signal, the locking signal **255** remains at a zero level from the time t_1 to the time t_2. Meanwhile, if the receiver 2 **210b** is able to acquire both the synchronization signal and the start signal, the locking signal **260** changes to logical (1) level from the time t_1 to the time t_2 indicating the receiver lock. If during the reception time of the encoded data **190b**, the receiver 2 **210b** is not able to acquire either the synchronization signal or the start signal, the locking signal **260** remains at a zero level from the time t_3 to the time t_4. Meanwhile, if the receiver 1 **210a** is able to acquire both the synchronization signal and the start signal, the locking signal **255** changes to logical (1) level from the time t_3 to the time t_4 indicating the receiver lock. Finally, if during the reception time of the encoded data **190c**, the receiver 1 **210a** and receiver 2 **210b** both acquire the synchronization signal and the start signal, the locking signals **255** and **260** change to a logical (1) level from the time t_5 to the time t_6 indicating both the receiver 1 **210a** and receiver 2 **210b** are locked.

[0057] Once the lock signal is present at the receiver **210a**, **210b**, **... 210n**, the data stream of the serialized encoded data **217a**, **217b**, **... 217n** of the chosen receiver **210a**, **210b**, **... 210n** is transferred to and retained within

the data register **235**. The de-interleave circuit **240** extracts the digital data with the included error correction codes from the data register **235** and rearranges the digital data to align the appropriate contiguous data segments are now placed correctly. The de-interleaved digital data is transferred to the error detection and correction circuit **245**.

[0058] The error detection and correction circuit **245** evaluates the digital data for errors and if the data is correct or is correctable transfers the data **250** to external circuitry. If the data is not correctable, the ECC error signal **247** informs the diversity circuit that the data stream is corrupted and not correctable. The diversity circuit then searches the lock signals of each receiver **210a**, **210b**, **... 210n** to determine a next receiver having a lock signal. The diversity circuit then transfers the next data stream of serialized encoded data **217a**, **217b**, **... 217n** of the chosen receiver **210a**, **210b**, **... 210n** to the data register **235**. The digital data is again de-interleaved by the de-interleave circuit **240** and examined for errors by the error detection circuit **245**. If the data is not correctable, this process continues until an evaluation time period expires and the receiver **210a**, **210b**, **... 210n** having the valid lock signal is chosen to provide data **250** to the external circuitry.

[0059] As is known in the art, the diversity receiver **200** may include a digital signal processor. The digital signal processor, being a computing system, executes functions and processes being programs stored on data

storage medium for execution by the method shown in Fig. 9. A group of receiving transducers, such as antennas or photodiodes, receive (Box **300**) broadcast signals modulated with encoded data. The broadcast signals induce electrical signals in the receiving transducers that are conveyed to the digital signal processor. The digital signal processor will amplify and condition (Box **305**) the electrical signal to extract the encoded data from each of the group of receiving transducer, which is received and retained (Box **310**) for further processing. A data stream counter (**x**) is initialized (Box **315**) to select one of the data streams of encoded data extracted from the broadcast signal from one of the receiving transducers. The data stream is examined to detect the clock synchronization signal to synchronize (Box **320**) the receiving clock of the diversity receiver with the transmitted synchronization signal. The data stream is then examined to detect (Box **325**) the start signal to indicate the beginning of the interleaved digital data with the included error correction codes. If the synchronization signal and the start signal are both detected (Boxes **320** and **325**), the receiver is said to be locked. The receiver lock is then determined (Box **330**). If the receiver is not locked, the data stream counter is incremented (Box **335**) the next data stream indicated by the data stream counter is examined to determine if the data stream is locked (Boxes **320** and **325**). The data stream counter is repetitively incremented (Box **335**) and the data stream indicated by the data stream counter is examined for locking (Boxes **320** and **325**) until a locking is determined.

[0060] Once the receiver is locked, an evaluation time period is initialized (Box **340**) and the data stream of the encoded data from the receiver that achieved the data lock is selected (Box **345**) for evaluation. The encoded data is rearranged to place the data segments in their appropriate contiguous order to de-interleave (Box **350**) the encoded data. The selected encoded data is then checked for errors and if needed and if possible, the data is corrected (Box **355**).

[0061] If the encoded data is determined (Box **360**) to be uncorrectable, the data stream counter is incremented (Box **335**) and the data stream indicated by the data stream counter is evaluated (Boxes **320** and **325**) as locked. The data stream from the receiver selected pointed to by the data stream counter is evaluated (Box **355**) for correct or correctable data until correct or correctable is determined (Box **360**) to be present in the data stream of the encoded data. If the evaluation time is determined (Box **365**) not to have expired, the remaining segments of the data stream are continually evaluated (Box **355**) for correct or correctable data and the data stream selected by the data stream counter remains as the current data stream. When the evaluation time is determined (Box **365**) to have expired, the data stream is transferred (Box **370**) to external circuitry and the process begins again with the reception of the broadcast signal having the next frame of the encoded data.

[0062] Fig. 10 illustrates the timing of the communication system of this invention. The communication system of this invention is structured to have a pipeline of frames **402a**, **402b**, ..., **402n** of the digital data **400** that is being transferred to the transmitter system. Each frame **402a**, **402b**, ..., **402n** of the digital data **400** has an error correction code generated and included within the frame **407a**, **407b**, ..., **407n** to form the frames of encoded data **405**. The encoded data **405** has the synchronization and start signals appended for form the frames **412a**, **412b**, ..., **412n** transmit data **410**. The transmit data **410** modulates a fundamental frequency (RF or Infrared), which is then radiated to the environment.

[0063] The radiated signal is received and extracted by multiple antennas and receivers and the frames **417a**, **417b**, ..., **417n** and **422a**, **422b**, ..., **422n** of received encoded data **415** and **420** is retained in multiple buffer circuits

[0064] Buffer diversity basically refers to the instantiation of more than one set of receiving buffers to perform the acquisition task in parallel. In this case there are two antennas and receivers capturing the modulated signal with the encoded data. The data **415** and **420** extracted by the receiver is stored in the buffer circuits for further processing. The two Buffers contain the same data symbol stream **417a**, **417b**, ..., **417n** and **422a**, **422b**, ..., **422n** from the two different receiver units. Ideally these two buffers should

contain the same data but in practice, interference will cause these two buffers to be corrupted differently.

[0065] The error detection and correction circuit **245** of Fig. 6 examines the data **417a**, **417b**, ..., **417n** and **422a**, **422b**, ..., **422n** sequentially to establish the integrity of the data symbols received. The error detection and correction circuit **245** determines if the first data stream **415** is correct or correctable. If the data is correct or correctable the data stream **415** is correct or correctable, the corrected frames **427a**, **427b**, ..., **427n** of the data stream **425** of the first buffer is stored as the frames **432a**, **432b**, ..., **432n** of the data stream **430** in a "first-in-first-out" register. The data frames **437a**, **437b**, ..., **437n** of data stream **435** are the transferred to external circuitry.

[0066] If however, the data stream **415** of the first buffer is not correctable, the frames **422a**, **422a**, ..., **422a** of the data stream **420** of the second buffer is evaluated for correct or correctable data. If the data is correct or correctable the data stream **420** is correct or correctable, the corrected frames **427a**, **427b**, ..., **427n** of the data stream **425** of the first buffer is stored as the frames **432a**, **432b**, ..., **432n** of the data stream **430** in a "first-in-first-out" register. The data frames **437a**, **437b**, ..., **437n** of data stream **435** are the transferred to external circuitry.

[0067] Refer to Fig. 11 for a discussion of the second embodiment of this invention. The modulated broadcast signal **150** is acquired by a number

of transducers **505a**, **505b**, **..**, **505n**. The transducers **505a**, **505b**, **...** **505n** are placed such that as the modulated broadcast signal **150** may be fading causing an electrical signal developed by the transducers **505a**, **505b**, **...** **505n** to vary with the intensity of the modulated broadcast signal **150**. As described in Figs. 1b and 5, the modulated broadcast signal **150** may be blocked by geographic obstacles such as mountains, hills or buildings. These blockages cause the phase and strength or intensity of the modulated broadcast signal **150** to vary as it arrives at each of the multiple transducers **505a**, **505b**, **...** **505n**.

[0068] The electrical signals induced to the transducers **505a**, **505b**, **...** **505n** are transferred to a transducer switch **507**. The transducer switch **507** receives an transducer select line **532** which, based on a priority setting of the transducers, selects one of the multiple transducers **505a**, **505b**, **...** **505n**. The electrical signal of the selected transducer of the multiple transducers **505a**, **505b**, **...** **505n** is transferred through the transducer switch **507** to the amplification, conditioning, and evaluation circuit **515** within the receiver **510**. The amplification, conditioning, and evaluation circuit **515** amplifies the electrical signal and removes the fundamental transmit signal from the electrical signal to extract the serialized encoded data. The amplification, conditioning, and evaluation circuit **515** further evaluates the characteristics of the electrical signal from the selected transducer of the multiple transducers **505a**, **505b**, **...** **505n** to determine whether the quality of the electrical signal will allow the

extraction of the serialized encoded data. The amplification, conditioning, and evaluation circuit **515** generates an RF quality signal **519** containing results of the evaluation of the characteristics of the electrical signal.

[0069] The serialized encoded data is transferred to the clock synchronization circuit **525**, where the synchronization signal is detected and the receiver is synchronized to the frame clock **127** of Fig. 4. When the synchronization signal is detected, a synchronization locking signal **527** for the receiver **510** is generated indicating that the receiver **510** has achieved synchronization.

[0070] The serialized encoded data is also transferred to the start/stop circuit **520**. The start/stop circuit **520** examines the serialized encoded data to detect the start signal within each frame of the encoded data. When the start signal is detected, the start/stop circuit **520** the receiver **510** provides a start signal **522** indicating the beginning of the interleaved digital data with the included error correction code. The combination of the synchronization locking signal **527** and the start signal **522** are combined to form the lock signal as described above.

[0071] An example of the evaluation of the characteristics of the electrical signal from the selected transducer of the multiple transducers **505a**, **505b**, **... 505n** is shown in Fig. 13. The amplification, conditioning, and evaluation circuit **515** evaluates the amplitude of the demodulated electrical signal **700** from the selected transducer of the multiple

transducers **505a**, **505b**, **... 505n**. The demodulation removing any fundamental frequency from induced electrical signal. The amplification, conditioning, and evaluation circuit **515** extracts the serialized encoded data by comparing the demodulated electrical signal **700** to a reference voltage level **705**. If the amplitude **715** and **730** of the demodulated electrical signal **700** is greater than the reference voltage level **705**, the serially encoded data stream **710** changes from a first logic level to a second logic level, as shown in the pulses **725** and **740**. The pulse width **720** and **735** of the pulses **725** and **740** being determined by the amount of time that the demodulated electrical signal **700** remains at a voltage level greater than the reference voltage level **705**.

[0072] If the amplitude **715** of the demodulated electrical signal **700** is greater than the reference voltage level **705** for period of time **720** such that the pulse width **725** of the serially encoded data stream **710** permits correct detection of the serially encoded data **710**, the RF quality signal **519** indicates that the serialized encoded data **710** is adequate for reception. Alternately, if the amplitude **730** of the demodulated electrical signal **700** is not greater than the reference voltage level **705** for a period of time **735** sufficient to guarantee a pulse width **735** of the serially encoded data **710** that permits correct detection of the serially encoded data **710**, the RF quality signal **519** indicates that the serialized encoded data **710** is not adequate for reception. If the RF quality signal **519** indicates that the serialized encoded data **710** is not adequate for

reception, the transducer select signal **750** changes state **755** to select an alternate transducer.

[0073] Returning to Fig. 11, the data stream of the serialized encoded data **517**, the RF quality signal **519**, and the lock signal (synchronization locking signal **527** and start signal **522**) for the receiver **510** are the input signals for the diversity circuit **530**. The diversity circuit **530** determines that the electrical signal is of sufficient quality that the extracted serialized encoded data is valid and the receiver is synchronized to the transmitted synchronization locking signal and has detected the start signal. If the transducer having the highest priority value of the multiple transducers **505a**, **505b**, **... 505n** chosen does not have an electrical signal to guarantee a good extraction of the serialized encoded data or a lock signal, the priority value for the selected transducer is lowered. The diversity circuit **530** then reevaluates the priority of the multiple transducers **505a**, **505b**, **... 505n** and recodes the transducer select signal **532** to select a next of the multiple transducers **505a**, **505b**, **... 505n** with the highest priority value. The diversity circuit **530** selects each next highest priority transducer until a lock signal **527** is present.

[0074] Once the lock signal **522** is present at the receiver **510** and the receiver characteristic signal **522** indicates an adequate signal, the data stream of the serialized encoded data **517** of the receiver **510** is transferred to and retained within the data register **535**. The de-interleave

circuit **540** extracts the digital data with the included error correction codes from the data register **535** and rearranges the digital data to align the appropriate contiguous data segments are now placed correctly. The de-interleaved digital data is transferred to the error detection and correction circuit **545**.

[0075] The error detection and correction circuit **545** evaluates the digital data for errors and if the data is correct or is correctable transfers the data **550** to external circuitry. If the data is not correctable, the ECC error signal **547** informs the diversity circuit that the data stream is corrupted and not correctable. The diversity circuit then lowers the priority value for the selected transducer. The diversity circuit the reevaluates the priority of the multiple transducers **505a**, **505b**, **... 505n** and recodes the transducer select signal **532** to select a next of the multiple transducers **505a**, **505b**, **... 505n** with the highest priority value. The diversity circuit **530** selects each next highest priority transducer until the data extracted from the electrical signal of the selected transducer is correct or correctable.

[0076] As described above, the diversity receiver **200** may include a digital signal processor. The digital signal processor executing functions and processes being programs stored on data storage medium for executing the method shown in Fig. 12. A receiving transducer of a group of receiving transducers, such as antennas or photodiodes, has a transducer priority set (Box **600**). The transducer having the highest priority is

selected (Box **605**) to receive (Box **610**) broadcast signals modulated with encoded data. The broadcast signals induce electrical signals in the selected receiving transducer, which are conveyed to the digital signal processor. The digital signal processor will amplify and condition (Box **615**) the electrical signal to extract the encoded data from each of the group of receiving transducers, which is received and retained for further processing. The electrical signal from the selected receiving transducer is further evaluated (Box **620**) to determine if the characteristics such as the amplitude as described in Fig. 13 is sufficient to provide a correct data stream. The results of the evaluation (Box **620**) is examined (Box **625**) for suitability. If the electrical signal from the selected receiving transducer is not sufficient, the priority of the selected transducer is adjusted (Box **635**) and the transducer with the next highest priority is then selected (Box **605**) until an evaluation (Box **620**) indicates that the electrical signal is sufficient to provide a correct serially encoded data stream. The serially encoded data stream is received (Box **630**) and the data stream is examined (Box **640**) to detect the clock synchronization signal to synchronize the receiving clock of the diversity receiver with the transmitted synchronization signal. The data stream is then examined to detect (Box **645**) the start signal to indicate the beginning of the interleaved digital data with the included error correction codes. If the synchronization signal and the start signal are both detected (Boxes **640** and **645**), the receiver is said to be locked. The receiver lock is then determined (Box **650**). If the

receiver is not locked, the priority of the selected transducer is adjusted (Box **635**) and the transducer with the next highest priority is selected **605**. The data stream counter is repetitively incremented (Box **635**) and the data stream resulting from the next selected transducer is examined for locking (Boxes **620** and **625**) until a locking is determined.

[0077] Once the receiver is locked, the encoded data is rearranged to place the data segments in their appropriate contiguous order to de-interleave (Box **655**) the encoded data. The selected encoded data is then checked for errors and if needed and if possible, the data is corrected (Box **660**).

[0078] If the encoded data is determined (Box **660**) to be uncorrectable, the priority of the selected transducer is adjusted (Box **635**) and the transducer with the next highest priority is selected **605**. The data stream from the selected transducer is evaluated (Box **660**) for correct or correctable data until correct or correctable is determined (Box **665**) to be present in the data stream of the encoded data. The data stream is transferred (Box **670**) to external circuitry and the process begins again with the reception of the broadcast signal having the next frame of the encoded data.

[0079] In the second embodiment of the invention, the switching of the transducer (antenna or photodiode) must be sufficiently fast that block of the received data are maintained. Maintaining of the blocks of the

received data permits a continuity of the data. In an audio application, this continuity prevents unwanted noise or distortion of the audio stream.

[0080] Further the priority of the transducers permits the allowance for different losses for the multiple paths of the broadcast signals to the different transducers. A transducer having lower loss due to multiple path interference may be selected primarily over one with more loss.

[0081] While this invention has been particularly shown and described with reference to the preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made without departing from the spirit and scope of the invention.

[0082] The invention claimed is: